Laser Cleaning of Glass

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ABSTRACT

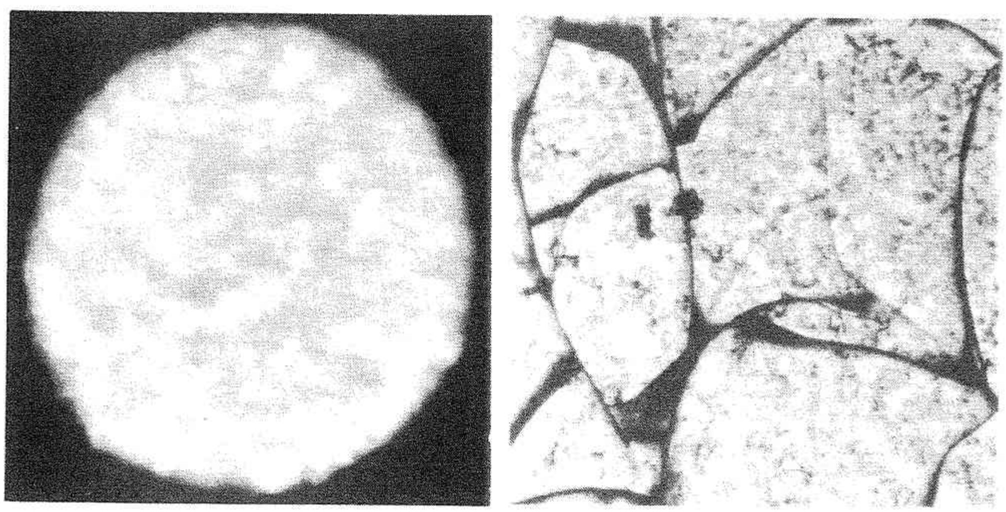
The pulse lasers, YAG-, CO_2-, and N_2-lasers, are examined for use in the cleaning of glass. Cleaning is found to be due to the evaporation and sputtering of stains on the glass by the heat energy of the laser light. Only the N_2 laser can be used for the cleaning of the exit surface of the glass (the opposite side to the laser). A laser with a high peak power of about $10^6\, J/s$ and short-pulse duration below $100\, ns$ is found to be necessary in practice.

The cleaning of a glass surface is important in many industrial fields. In particular, the cleaning of the outside surface of window glass in buildings is worth notice because the proportion of windows in the walls of buildings has been increasing, and buildings themselves have become progressively larger and taller. Furthermore, window glasses are usually mounted in a frame in a building, so that opening and shutting cannot be done, which makes cleaning very difficult. For this reason, mechanical-, chemical- and physical-cleaning techniques have been proposed, and some of them are now in practical use. Cleaning by means of ultrasound is so far the only method that enables us to clean not only the entrance surface of the glass (the laser side) but also the exit surface of the glass (the opposite side to the laser side). This method, however, has a disadvantage that the glass to be cleaned has to be submerged under water or at least be put into a special container.

Another possible method may be a 'laser cleaning'. In this case, we can easily make the outside of the window glass clean from the inside of the building without touching the glass. Laser cleaning depends on evaporation or sputtering by the energy of the laser light. In this paper, we report briefly a preliminary experiment on laser cleaning. The cleaning efficiency was examined at various wavelengths, pulse durations, and peak powers of the laser light.

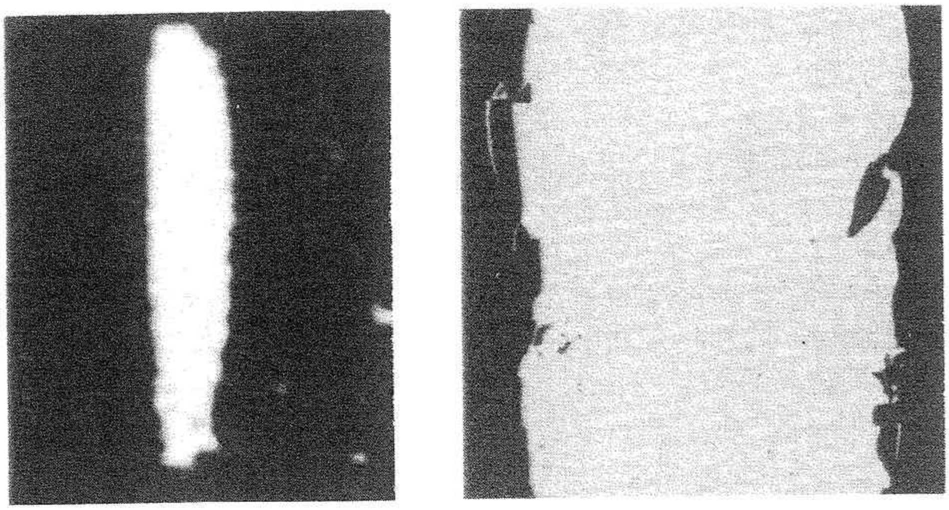
Three kinds of laser, a YAG laser (pulse energy 1 J, pulse duration 0·2 ms), an N_2 laser (pulse energy 6 mJ, pulse duration 6 ns) and a TEA CO_2 laser (pulse energy 3 J, pulse duration 100 ns) were used in this experiment. The laser light was focused on the glass surface by a lens between the laser and the glass. Stains were made with black marking ink on the glass surface. The energy intensity of the laser light on the glass surface was varied by changing the position of the lens. The exit surface of the glass was cleaned by YAG-laser or N_2-laser irradiation. But, in the case of the CO_2 laser, only the entrance surface of the glass was cleaned because the CO_2-laser light is not transmitted by the glass. All the cleaning was done by only one shot of laser irradiation. Glass of thickness 5 mm was used for YAG-laser cleaning and glass of thickness 3 mm for N_2-laser cleaning.

Figure 1 shows an example of YAG-laser cleaning: (*a*) naked-eye observation and (*b*) microscopical observation (×50). The energy intensity of the laser light on the irradiated surface is 60 J/cm^2. Some cracks are observed microscopically (Fig. 1(*b*)). It was observed that the threshold-energy intensity required for effective cleaning was about



(a) (b)

Fig. 1. The marks of YAG laser irradiation. (*a*) naked eye observation, (*b*) microscopic observation (×50).



(a) (b)

Fig. 2. The marks of N_2 laser irradiation. (*a*) naked eye observation, (*b*) microscopic observation (×50).

90 J/cm^2. Many cracks were then produced in the case of effective cleaning by YAG laser, which could be seen clearly with the naked eye. These values were almost the same for glasses of different thickness. This is due to the fact that glass has a high transmittance to YAG-laser light.

Figure 2 shows an example of N_2-laser cleaning: (*a*) naked-eye observation and (*b*) microscopical observation (×50). The energy intensity of the laser light on the irradiated surface was estimated to be 0·2 J/cm^2 on the assumption that about half the energy was converted into heat within a glass plate of 3-mm thickness. In this case, no cracks were observed on the irradiated surface. This is confirmed for energy intensities of up to 0·5 J/cm^2. The threshold-energy intensity for N_2-laser cleaning was about 0·1 J/cm^2. This value is about one-thousandth of that of YAG-laser cleaning. The same results as those for N_2-laser cleaning were obtained for CO_2-laser cleaning, that is, the threshold-energy intensity for CO_2-laser cleaning is about 0·5 J/cm^2, which is of the same order as the value for N_2-laser cleaning and, in addition, no cracks were observed. But, if the energy intensity increases to 3 J/cm^2, some cracks are produced as in the case of YAG-laser cleaning. The peak power of the laser light to obtain the threshold-energy intensity for effective cleaning was estimated to be 10^6 J/s for N_2-laser cleaning, 10^7 J/s for CO_2-laser cleaning, and 10^4 J/s for YAG-laser cleaning, respectively, that is, a high peak power above 10^6 J/s is required for ideal cleaning without any damage to the glass.

The differences in the threshold level for energy intensity or peak power and the production of cracks for each type of laser cleaning may be understood as follows. In N_2-laser cleaning and CO_2-laser cleaning, the stains on the glass surface are vaporized or scattered in a very short time (within a few tens ns). The glass surface is exposed to a high temperature for rather a long duration of 0·2 ms in YAG-laser cleaning. The pulse duration of the YAG laser is about 10^4 times as long as that of the N_2 laser or CO_2 laser. Thus, a large part of the light energy may be considered to be effectively used for the evaporation of the marking ink in the case of N_2-laser cleaning and CO_2-laser cleaning, whereas on the contrary, most of the energy of the YAG-laser light is accumulated in the thin layer of the glass surface. Furthermore, only a thin layer is heated since heat is not conducted far into the glass during the pulse of the YAG-laser irradiation.

In conclusion, either a TEA CO_2 laser or an N_2 laser can effectively be used for the cleaning of the entrance surface of the glass, but only an N_2 laser can be used for the exit surface. A YAG laser with a long pulse duration cannot be used practically for laser cleaning because of the production of cracks. A laser with a high peak power and short pulse duration is necessary for the practical cleaning of the glass without any damage in the form of cracks. For this reason, a YAG laser with a Q-switched pulse duration of a few tens of ns or a high-power excimer laser having a wavelength above 300 nm, which has a good transmittance through glass, may replace an N_2 laser.